PRELIMINARY GEOLOGIC RECONNAISSANCE
PUMPED STORAGE PROJECTS
KOKO CRATER AND KAAU CRATER SITES
OAHU, HAWAII

W.O. 3153-00 OCTOBER 22, 1993

FOR

OKAHARA & ASSOCIATES

APPENDIX E

C.W. ASSOCIATES, INC. dba
GEOLABS-HAWAII
Geotechnical Engineering, Geology and Environmental Services

October 22, 1993
W.O. 3153-00

Mr. Louis Lopez
Okahara & Associates
470 N. Nimitz Highway, Suite 212
Honolulu, Hawaii 96817

Dear **Mr. Lopez:**

Submitted herewith is our report entitled "Preliminary Geologic Reconnaissance, Pumped Storage Projects, Koko Crater and Kaau Crater Sites, Oahu, Hawaii."

Our work was performed in general accordance with the scope of services outlined in our fee proposal of July 20th.

Detailed discussion and recommendations are contained in the body of this report. If there is any point that is not clear, please contact our office.

Very truly yours,

C.W. ASSOCIATES, INC.
dba **GEOLABS-HAWAII**

Bob Y.K. Wong

Bob Y.K. Wong, P.E.
President

BYKW:RS:crc

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PRELIMINARY GEOLOGIC RECONNAISSANCE

PUMPED STORAGE PROJECTS

KOKO CRATER AND KAAU CRATER SITES

OAHU, HAWAII

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SUMMARY OF FINDINGS AND RECOMMENDATIONS

Based on reconnaissance level studies, the Koko Crater and Kaau Crater pumped storage projects appear to be feasible from a geotechnical standpoint provided certain geotechnical concerns can be addressed.

Tuff derived borrow materials at the Koko Crater site are expected to yield earthfill type material. This material may be suitable for earthfill dam construction provided concerns regarding the erodibility of the material on fill embankments can be addressed. Control of groundwater at the Koko Crater powerhouse site is expected to be a difficult and costly problem to overcome.

Construction of a concrete or rockfill dam at the Kaau Crater site appear to be viable alternatives. Basalt derived borrow material at the Maunawili lower reservoir site should provide a source of rockfill material suitable for dam construction at that location. Confined groundwater conditions in the area of the Kaau powerhouse and tunnels will likely present significant construction challenges.

The geologic setting of both sites is described in text followed by discussion of borrow materials, dam sites, reservoir construction, tunnel construction, powerhouse sites and potential geologic hazards.

INTRODUCTION

Preliminary geologic reconnaissance explorations for the proposed Koko Crater and Kaau Crater reservoir and pumped storage hydroelectric plant sites have been completed. Our exploration was performed in general accordance with our proposal, dated July 20th.

PROJECT CONSIDERATIONS

The main components of the proposed pumped storage projects are described in the Integrated Resource Plan prepared by Hawaiian Electric Company. There are two separate sites included in this project. The Koko Crater site is located on the southeast coast of Oahu, just east of Hawaii Kai. The proposed hydroelectric facility would include a reservoir in Koko Crater, a powerhouse located on the coast, a tunnel connecting the reservoir and the powerhouse, and a substation with transmission lines. A dam would be constructed across a gap in Koko Crater to create the reservoir. The dam would be approximately 160 feet high. It is anticipated that the reservoir would be designed with an interior liner. The powerhouse would extend to at least 50 feet below mean sea level. Water conductor tunnels are expected to have an inside diameter of 24 feet, and individual unit penstocks would be approximately 14 feet in diameter. Total tunnel lengths would be on the order of ½ mile.

The Kaau Crater site is located inland at the upper end of Palolo Valley on Oahu. The proposed hydroelectric facility would include an upper reservoir at Kaau Crater Reservoir, a lower reservoir in Maunawili valley, a power house, water conducting tunnels, and a substation with transmission lines. The dam at the crater site would be approximately 100 feet high, and the crater would be lined to conserve water. The lower reservoir would be contained by a dam of approximately 130 feet high, and approximately 2,670 feet long at the crest. The lower reservoir would also be lined to conserve water. The powerhouse would be constructed underground, at an elevation approximately 100 feet below the minimum operating level within the lower reservoir. Water conductor tunnels are expected to have an inside diameter of 18 feet, and individual unit penstocks would be approximately 10 feet in diameter. Total length for access tunnels, low pressure tunnels, vertical shafts and tailrace tunnels would be on the order of about 1½ miles.

PURPOSE AND SCOPE

The purposes of this reconnaissance have been to provide a preliminary assessment of geologic conditions at both sites and to evaluate potential geotechnical constraints for development of the subject project. Our scope of services has included the following:

1) Review of pertinent published and un-published geologic maps and reports available from our own files as well as from the U.S. Geologic Survey, University of Hawaii, etc.

2) Examination of stereopaired aerial photographs (Koko Crater site).

3) Reconnaissance of the sites by an engineering geologist from our office to map geologic conditions exposed at the sites.

4) Preparation of a report (6 copies) presenting our preliminary characterization of geologic conditions at the project sites, and an evaluation of potential geologic concerns. Preliminary geologic maps of both sites have been prepared showing the approximate extent of surficial deposits and mapping of bedrock units.

KOKO CRATER SITE

Site Description

The Koko Crate site is located on the southeast coast of Oahu, just east of Hawaii Kai as shown on the attached Project Location Map, Plate 1. Elevations on the rim of Koko Crater vary from about +500 feet Mean Sea Level (MSL) to about +1200 feet MSL. On the northeast side of the crater is a gap that currently provides a drainage course from the interior of the crater. Elevations in the interior of the crater range from about +240 feet MSL at the gap to about +320 feet MSL at the southwest side of the crater.

A botanical garden is located in the crater where a wide range of native and exotic plants are maintained. Interior and exterior side slopes of the crater are vegetated with scattered grasses and brush. Improvements in the crater appear to be limited to irrigation piping and various unpaved access roads.

The proposed powerhouse would be located south of the crater between Kalanianaole Highway and the coast. Topography in this area slopes very steeply from the highway to the sea level. A wave cut platform of variable width is located at about high tide level. Vegetation on the steep slope consists of sparse grasses with large areas exposing bare rock.

Regional Geology

Koko Crater is a compound tuff cone which is part of the Honolulu Volcanic series (Macdonald, 1970). Potassium-argon dating indicates that Koko Crater is about 32,000 years old. Koko crater is believed to have been formed by violent explosions that occurred when rising lava came in contact with sea water. Fragments of lava as well as fragments of older volcanic rock and coral were ejected and deposited as tuff. The gap at the northeast side of the crater probably resulted from trade winds blowing most of the ash toward the southwest.

Following the period of eruption, the crater has been modified by processes of weathering and erosion to create the current landform. Volcanic fragments in the tuff have been altered to palagonite through weathering processes. Tuff has eroded from the side slopes of the crater creating gullies and steep scarps. The eroded materials have been deposited as talus and alluvium on the interior and exterior of the crater.

Site Geology

A preliminary geologic map of the Koko Crater site is presented on the attached Plate 2. Based on our site reconnaissance and examination of aerial photographs, the approximate extent of surfical soil deposits, bedrock structure, and other geologic features have been depicted on the geologic map. Descriptions of the geologic mapping units are presented below:

Koko Tuff - Areas of the site underlain by Koko tuff are shown on the geologic map using the symbol "Rkt." The Koko tuff contains predominantly silt and sand size fragments of ash and volcanic rock. A darker colored cap of opal-cemented tuff is evident around the rim of the crater. Where the cap has been eroded away, the underlying, lighter colored palagonitized tuff is exposed. Following deposition, this tuff has been altered by weathering to palagonite. The palagonite tuff appears to be more easily eroded than the overlying opal-cemented tuff which tends to form the steep cliffs and scarps in the area.

The light brown palagonite tuff exposed in outcrops appears to be weak to moderately strong, highly fractured and varies from thinly to thickly bedded. The dark brown opal-cemented tuff also appears to be weak to moderately strong but appears to be moderately to occasionally fractured.

Structurally, the Koko Tuff is complex. The dominant structural feature is an antiform with an axis that corresponds roughly with the rim of the crater. In general, beds on the exterior of the crater dip away from the center of the crater whereas beds on the interior of the crater dip toward the center of the crater. A notable exception to this configuration is evident along the interior, northwest slope of the crater where the inward dipping beds appear to have been eroded away to expose outward dipping beds. Horizontally stratified tuff was observed in gullies in the northwest portion of the crater floor. This tuff probably represents some of the youngest tuff associated with Koko Crater.

Koko Basalt - Basaltic "aa" volcanic rock was exposed on both the northwest and southeast sides of the crater gap. These areas are shown on the geologic map using the symbol "Rkb." This volcanic rock appears to have chaotic structure with no evident bedding. The "aa" appears to consist of a dense mass of vesicular basaltic rock fragments.

Alluvium - Alluvium is soil material that has been deposited by flowing water. Portions of the study area that appear to be underlain by alluvium are indicated on the geologic map using the symbol "Ra." Alluvium was exposed in gullies eroded in the crater floor. At the crater gap, an exposure of alluvium over 20 feet thick was observed in the stream course consisting of sandy silt with gravel and cobbles. Elsewhere in the crater, gullies exposed alluvium consisting predominantly of sandy silt with cobbles and boulders. The alluvium generally appeared to be medium dense to dense although some porous gravel beds were observed.

Colluvium - Colluvium is material that is deposited by processes such as slope wash, sheet erosion, rock fall, etc. The transition slope on the interior of the crater between the relatively flat crater floor and the steep side slopes appears to be underlain by colluvium which is designated by the symbol "Rc" on the geologic map. The colluvium appears to contains predominantly of cobbles and boulders with some sandy silt matrix. Abundant boulders up to 10 feet in diameter were observed along the west side of the crater floor.

Colluvium was also mapped in a valley on the north side of Kalanianaole Highway near the proposed powerhouse location. The colluvium is estimated to be about 10 to 15 feet thick in this valley.

The more prominent valley extending west from Halona Blowhole does not appear to be underlain by colluvial deposits. Tuff was observed in the stream bed in this valley.

Landsliding - Evidence of rockfall and rock slides is visible on both the interior and exterior slopes of the crater. The dip slope conditions combined with undermining of the more easily eroded palagonite tuff appears to have resulted in rockfall and rock slides. Scarps resulting from these slope movements are shown on the geologic map using a hatchered line.

Photolineaments - Two linear valleys cross the proposed tunnel alignment near Kalanianaole Highway. Both valleys trend roughly perpendicular to the tunnel alignment. The trend of these valleys is somewhat anomalous when compared to the general drainage pattern in the area. As noted in the discussion regarding alluvial deposits, tuff was observed in the stream bottom of the northern valley. No signs of shearing and no significant difference in the makeup or structural orientation of the tuff were noted on either side valley. Macdonald (1970) interprets these landforms as remnants of the rim of an older tuff cone that has been almost completely eroded away by wave action. Additional investigation of linear valleys would be needed to these understand the origin of these landforms and the possible impact to the project.

Groundwater - Groundwater in the Koko Crater area is probably basal, or near sea level, groundwater. In such close proximity to the ocean, the basal water is likely saline but may have a thin upper zone of brackish water. Localized zones of perched groundwater may exist within the tuff due to variations in permeability; however, these are probably limited in extent.

DISCUSSIONS AND PRELIMINARY RECOMMENDATIONS

General

Based on our reconnaissance level exploration, the Koko Crater pump storage project appears to be feasible from a geotechnical standpoint provided certain geotechnical constraints can be addressed. Our comments regarding various aspects of the project are discussed below followed by comments regarding potential geologic hazards.

Project Construction

Borrow Materials - Considering the weak to moderately strong nature of the Koko Crater tuff, local borrow sites will likely yield earthfill-type material rather than rockfill material. As with any dam construction project, processing of borrow material will be necessary for use of tuff material as embankment fill. Sources of rockfill material exist off-site; however the cost of trucking these materials to the site is probably cost prohibitive.

Because the tuff consists predominantly of silt and sand size particles, tuff derived earthfill material will likely be highly erodible on embankments. Protective vegetation would likely be difficult to establish without irrigation. Tuff derived earthfill would also be susceptible to piping if seepage through the embankment were to occur.

Deposits of low permeability material suitable for dam clay core or reservoir lining were not observed during our site reconnaissance. Clayey silt soils, while having sufficiently low permeabilities for lining, appear to be scattered in occurrence and of limited thickness.

Alluvium in the crater appears to be a potential source of granular filter material. Processing of the alluvium would be needed to achieve an appropriate gradation for use as filter material.

Dam Site - To reduce the amount of settlement the dam will experience, over-excavation of the alluvial materials at the crater gap will likely be required. Alluvium at the crater gap was observed to be at least 20 feet thick where exposed in the stream course draining the crater. Tuff observed at the left and right dam abutments should provide adequate foundation support for dam construction. Where basalt is exposed at the dam abutments, probing should be performed to detect any voids or cavities. Depending on the location and size of voids, grouting or filling of voids with engineered fill may be needed.

Reservoir Construction - The tuff and alluvium within the crater, in general, appear to be highly permeable. Lining of the reservoir will be needed to reduce the potential for large losses of water through infiltration. Tuff and alluvium within the crater do not appear to be highly compressible and will likely provided adequate support for liner construction.

Tunnel Construction - Tunnel excavation in the weak to moderately strong tuff appears to be feasible using road headers, tunnel boring machines, or drill and blast methods. Considering the highly fractured, thinly bedded nature of the tuff, the need for temporary tunnel crown support should be anticipated. Near vertical road cuts up to 30 feet high along Kalanianaole Highway appear to have performed reasonably well for many years. Based on the performance of the existing road cuts along Kalanianaole Highway, vertical rock faces should have very good standup time. However, this should be further evaluated during detail design.

Where tunneling extends below sea level, basal groundwater will be encountered. Due to the high permeability of the tuff, very high rates of flow would enter underground openings below sea level. Any excavations below sea level will require carefully designed and constructed groundwater control measures such as grout curtains and dewatering.

Powerhouse Site - Construction concerns for the proposed powerhouse site will be similar to those described for tunneling. Control of groundwater infiltration will likely be the most difficult and costly problem to overcome. For larger underground openings, adverse bedding may be of concern. Well developed bedding planes in the tuff dip at an inclination of about 10 degrees toward the southeast at the powerhouse location. Large southeast facing excavation faces may be subject to bedding plane block failure unless appropriate support measures are used.

Geologic Hazards

Slope Stability - As presently planned, it does not appear that the proposed project would adversely affect stability of the slopes in the area. Areas of rockfall and rock sliding are located well above the anticipated reservoir level. The possibility of rockfall and rock sliding will continue to exist on the steep slopes above the reservoir, primarily on the west and northwest sides of the reservoir. Future studies should be conducted to evaluate the potential for a large rockfall or rock slide to impact the reservoir and consider the resulting consequences from wave action or temporarily elevated reservoir levels.

Seismicity - Except for the island of Hawaii, the Hawaiian Islands are not considered a highly active seismic area. Under the Uniform Building Code, the island of Oahu has been designated as Seismic Zone 2A which indicates that for design purposes a horizontal peak ground acceleration of 0.15g should be used. The Uniform Building Code establishes minimum seismic design criteria for any structures constructed in such a zone for resistance to deformation and damage resulting from such strong ground motion. Therefore, any structures that will be built as part of the project should be designed with consideration of the hazards of seismic activity.

Volcanic Activity - As noted in the text of the report, Koko Crater is believed to be approximately 32,000 years old. Most geologists generally consider volcanoes active if they have erupted within the last 11,000 years and volcanoes that have erupted within the last 2 million years are considered potentially active. By this definition, Koko Crater can be considered a potential active volcano.

In general, the northwestern Hawaiian Islands are the oldest while the southeastern islands are the youngest. Although Koko Crater can be considered potentially active, the trend of activity in the Hawaiian Islands would suggest that the likelihood of renewed volcanic activity on Oahu during the life span of the project is relatively low.

Inundation - Inundation, or flooding, can originate from landward water courses or from tsunami. The Koko Crater reservoir site is located sufficiently inland and at a high enough elevation that the possibility of inundation by tsunami is remote. Intense rain storms can cause localized flash flood conditions in the drainage courses on the flanks of Koko Crater that may transport mud and rock debris.

Depending on the actual location of the powerhouse and substation, these facilities could be subject to inundation by tsunami. The zone between Kalanianaole Highway and the coast is within the potential inundation area shown on tsunami evacuation maps.

Ground Subsidence - Ground subsidence is generally the result of either consolidation of soft or loose subsoils or of the collapse of voids in the subsurface. The project site does not appear to be underlain by soft or loose soils; therefore, ground subsidence resulting from the consolidation of soft or loose subsoils does not appear to be a consideration for the subject project. Tuff rock formations generally do not contain voids or cavities that may be subjected to collapse. Basalt foundation materials should be probed and treated as noted in the dam site section of this report.

KAAU CRATER SITE

Site Description

Kaau Crater, the upper reservoir site, is located at the head of Palolo Valley on the southwest side of the Koolau mountain range. The lower reservoir site is located in Maunawili Valley on the northeast side of the Koolau range. Both the upper and lower reservoir sites are shown on the attached Project Location Map, Plate 3.

Elevations on the rim of Kaau Crater vary from about +1700 to +1800 feet MSL. On the southeast side of the crater is a gap that currently provides a drainage course from the interior of the crater. The elevation at the gap is about +1460 feet MSL.

The floor of Kaau Crater is a swampy area vegetated with grasses, brush and trees. Interior and exterior side slopes of the crater are vegetated with dense brush and trees. Improvements in the area of Kaau Crater appear to be limited to high voltage transmission towers located on the southwest rim.

The Maunawili reservoir site is located in Maunawili Valley about 1 mile north of Kaau Crater. Conceptual plans suggest that the dam would be located at about elevation +600 feet MSL.

The Maunawili reservoir site is densely vegetated with trees and brush. Improvements in this area include an unpaved access road located downstream of the tentative dam site, high voltage transmission towers on the ridge to the south of the dam site, and Pikoakea Spring and Clark Tunnels are located near the tentative left abutment.

Regional Geology

Kaau Crater is associated with the Honolulu Volcanic series (Macdonald, 1970) and is believed to have been blasted out of Koolau basalt by explosive eruptions. While the Koolau basalts that form the rim of the crater are estimated to be over 2 million years old, the eruptions that formed the crater have been dated as recent as about 32,000 years old.

Following the period of eruption, the crater has been modified by processes of weathering and erosion to create the current landform. Basalt rock has eroded from the side slopes of the crater creating gullies. The eroded materials have been deposited as talus and alluvium on the interior of the crater.

The Maunawili reservoir site is located in an area mapped as Koolau dike complex rock (Stearns, 1966). The Koolau dike complex is basaltic volcanic rock having nearly vertical structure resulting from repeated intrusions of lava. A contact between the near-horizontally structured Koolau basalt to the south and the vertically structured Koolau basalt has been mapped near the base of the Pali or steep cliff on the north side of the Koolau range.

Site Geology

A preliminary geologic map of the Kaau Crater and Maunawili sites is presented on the attached Plate 4. Based on our site reconnaissance and examination of aerial photographs, the approximate extent of surfical soil deposits, bedrock structure, and other geologic features have been depicted on the geologic map. Descriptions of the geologic mapping units are presented below.

Koolau Dike Complex - Portions of the study area underlain by the Koolau dike complex are shown on the geologic map using the symbol "Tkdc." Rock of the Koolau dike complex generally consists of gray to black near vertical basalt dikes ranging from several inches to several feet thick. Only limited exposures of rock were visible at the Maunawili site. In stream bottoms and at Pikoakea Spring, the basalt exposed appeared to be strong to very strong, with few vesicals, and range from highly to occasionally fractured.

Koolau Basalt - The crest of the Koolau range and the area around Kaau Crater are underlain by Koolau basalt as indicated on the geologic map using the symbol "Tkb." Koolau basalt varies from dense to very vesicular and typically has nearly horizontal structure. Basalt exposures at the gap in Kaau Crater were moderately weathered, highly fractured with massive structure. "Stair stepping" patterns on the cliff faces of the Koolau range suggest alternating layers of dense, massive basalt and layers of less dense, highly fractured or more erodible basalt.

Alluvium - Alluvium is soil material that has been deposited by flowing water. Portions of the study area that appear to be underlain by alluvium are indicated on the geologic map using the symbol "Ra." Alluvium was exposed in gullies eroded in the crater floor and in stream courses in the Maunawili valley.

Alluvium within Kaau Crater probably consists of silt and clay with some interlayered organic material or peat. The alluvium in the crater was observed to be saturated and soft. Men walking across the crater floor sink into the soft silt and clay 3 to 6 inches. Beneath the soft silts and clays, coarser grained alluvium may exist in the crater.

Stream courses in the Maunawili reservoir area have been numbered Nos. 1 through 3 on the geologic map for discussion purposes. Where the access road crosses Stream No. 1, in-situ basalt appears to be exposed in the stream bottom. Small pockets of alluvium may be present upstream of the access road; however, the stream generally appears to be in an erosive mode. Where the access road crosses Stream No. 2, alluvial in-filling of the valley was approximately 150 feet wide and could be on the order of 30 feet or more in thickness. The alluvium exposed in the stream bank consisted of dense clayey sand and gravel. Several hundred feet upstream of the access road, near Pikoakea Spring, the alluvial deposit narrowed to only about 20 feet wide with an estimated thickness of about 10 feet. In-situ basalt was exposed in Stream No. 3 where the access road crosses the stream.

Colluvium - Colluvium is material that is deposited by processes such as slope wash, sheet erosion, rock fall, etc. The transition slope on the interior of the crater between the relatively flat crater floor and the steep side slopes appears to be underlain by colluvium which is designated by the symbol "Rc" on the geologic map. The colluvium probably contains predominantly cobbles and boulders with sand, silt and clay matrix.

Landsliding - Evidence of debris flows or debris avalanches is visible on steep slopes in the area of the Kaau Crater and on the Pali upslope of the Maunawili site. In general, these landslides appear to have occurred where a thin layer of soil and weathered rock in very steep swales or gullies becomes saturated and moves down slope as an incoherent mass of soil and rock debris.

Groundwater - Groundwater in the Kaau Crater area was observed to be very near the ground surface. Low permeable silts and clays in the crater appear to have formed a perched ground water condition in the crater. The vertical and lateral extent of this layer is not known at this time and should be further evaluated. At the time of our site visit, runoff from the crater through the crater gap was visually estimated at about 60 gallons per minute.

Groundwater in the Koolau basalt surrounding Kaau Crater probably occurs in two forms: 1) groundwater perched in more permeable horizontal layers in the basalt; and 2) basal groundwater at great depth below the crater. In the area of the Maunawili reservoir, significant quantities of dike impounded groundwater may exist within the basaltic rock. Groundwater flowing from Pikpakea Spring is probably dike impounded groundwater.

CONCLUSIONS AND RECOMMENDATIONS

General

Based on our reconnaissance level exploration, the Kaau Crater pumped storage project appears to be feasible from a geotechnical standpoint provided certain geotechnical constraints can be addressed. Our comments regarding various aspects of the project are discussed below followed by comments regarding potential geologic hazards.

Project Construction

Borrow Materials - Spur ridges in the proposed Maunawili reservoir area appear to be potential sources of basalt rockfill material. Depending on the configuration of the reservoir, removal of spur ridges could enhance reservoir capacity. Basalt rock on the rim of Kaau Crater should also have characteristics appropriate for use as rock fill; however, the high visibility of the crater rim may be of concern.

Deposits of low permeability material suitable for dam clay core or reservoir lining were not observed in our reconnaissance of the Maunawili reservoir area. Clayey silt residual soils, while having sufficiently low permeabilities for lining, appear to be of limited thickness and do not appear to occur in sufficient quantities for practical use.

Silts and clays within Kaau Crater may be suitable for use as liner material for the Kaau reservoir. These materials currently function to some extent as a natural liner in the crater. It is possible that these materials could be processed and reworked to form a more uniform and reliable liner. Soft soil and shallow groundwater conditions would present difficulties that would need to be overcome to process the silts and clays.

Alluvium in the Maunawili reservoir area may be a potential source of granular filter material although the quantities available appear to be limited upstream of the access road. Basalt rock, if crushed and screened, may be a potential source of filter material.

Dam Site - To reduce the amount of settlement the Maunawili dam will experience, overexcavation of the alluvial materials will likely be required. Alluvial deposits upstream of the access road appear to be limited in extent and, therefore, do not appear to present a significant constraint to dam construction. Once basalt rock foundation conditions are exposed, probing to detect possible voids in the rock may be required. Depending on the size and location of voids or cavities, grouting or filling with compacted fill may be appropriate to improve foundation support. With appropriate keying benching, and probing as noted above, basaltic rock at the left and right dam abutments should provide adequate foundation support for dam construction.

Moderately weathered basalt rock is exposed across the bottom and sides of the gap in Kaau Crater. With appropriate keying, benching and probing, the basaltic rock should provide adequate support for a rock fill or concrete dam. It should be noted that the existing exterior slopes at the gap of the crater is relatively steep. The steep slope may present a constraint for the downstream slope of the dam.

<u>Reservoir Construction</u> - Although the silt and clay in the bottom of Kaau Crater appears to have low permeability characteristics, basalt rock and colluvial transition slopes around the perimeter of the crater floor may have high permeability. Lining of the reservoir will be needed to reduce potential large losses of water through infiltration. Alluvium within the crater appears to be highly compressible and may experience significant settlement under reservoir loading. Depending on the thickness of the compressible silts and clays, reworking of the compressible materials may reduce the potential settlements to acceptable levels. A combination of reworking the compressible materials, with the use of a lining system that can accommodate some settlement, may be needed.

Alluvium and basalt rock at the Maunawili site appears to have high permeability characteristics, therefore, lining of this reservoir should be anticipated.

<u>Tunnel Construction</u> - Tunnel excavation in the basaltic rock appears to be feasible using conventional drill and blast methods. Considering the variable nature of the basalt, the need for temporary tunnel crown support on portions of the tunnel should be anticipated. Zones of dense, moderately fractured rock should have adequate standup time on near vertical faces without temporary support.

Abrupt changes in groundwater levels may be encountered during tunneling through basalt of the dike complex. Vertical discontinuities in the dike complex often contain zones of shearing and clay gouge that can act as groundwater barriers. Appropriate exploration and tunneling methods will need to be used to reduce potential construction and safety problems associated with sudden, large volume flows of groundwater and zones of sheared rock.

Powerhouse Site - Siting of the powerhouse within the dike complex will likely place the powerhouse below the confined groundwater level. Control of groundwater infiltration by grouting and dewatering will most likely be needed to permit construction.

Geologic Hazards

Slope Stability - Areas of debris flows and debris avalanches are located above both reservoir sites. The volumes of material involved in these types of slope movements are likely to be small; therefore, a significant impact on reservoir levels is not anticipated. Project facilities should be sited outside potential debris flow paths. For example, the inlet/outlet structure at the Kaau Crater should be sited toward the center of the crater, beyond the toe of colluvial transition slope on the north side of the crater.

Seismicity - Seismic conditions for the Kaau site are as described in the Koko Crater "Seismicity" section.

Volcanic Activity - Conditions with respect to volcanic activity at the Kaau site are similar to those describe in the Koko Crater volcanic activity section.

Inundation - Inundation, or flooding, can originate from landward water courses or from tsunami. The Kaau Crater and Maunawili reservoir sites are sufficiently inland and at high enough elevations that the possibility of inundation by tsunami is non-existent. Intense rain storms can cause localized flash flood conditions in the drainage courses on the flanks of Kaau Crater and upslope of the Maunawili site that may transport mud and rock debris.

Ground Subsidence - Ground subsidence is generally the result of either consolidation of soft or loose subsoils or of the collapse of voids in the subsurface. As noted in previous sections of this report, appropriate investigation and treatment of compressible materials and potential cavity areas will be required to reduce the potential for problems of this type to acceptable levels.

ADDITIONAL SERVICES

This preliminary assessment of geologic conditions and geotechnical constraints has been based on a reconnaissance level exploration. Site specific geotechnical investigations should be performed to characterize actual site conditions and develop recommendations for the projects.

LIMITATIONS

The preliminary findings and recommendations submitted in this report are based in part upon information obtained from points of observation in the field. Variations of conditions between the field data points may occur; and the nature and extent of these variations may not become evident until additional exploration or construction is performed. If variations then appear evident, it will be necessary to re-evaluate the recommendations provided in this report.

Elevations discussed in this report were determined by interpolation from elevation points on U.S.G.S. Topographic Maps. The physical location and elevation of the field data points should be considered accurate only to the degree implied by the method used.

The geologic contacts shown on the attached geologic maps are based on reconnaissance level mapping and as such are very approximate and subject to interpretation.

This report has been prepared for the exclusive use of Okahara & Associates and their consultants for specific application to the preliminary design of the project in accordance with generally accepted geotechnical engineering principles and practices. No warranty is expressed or implied.

PLATES

The following plates are attached and completes this report:

Plate 1	-	Project Location Map, Koko Crater Site
Plate 2	-	Preliminary Geologic Map, Koko Crater Site
Plate 3	-	Project Location Map, Kaau Crater Site
Plate 4	-	Preliminary Geologic Map, Kaau Crater Site

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Respectfully submitted

C.W. ASSOCIATES INC.
dba **GEOLABS-HAWAII**

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GENERAL PROJECT LOCATION

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PROJECT LOCATION MAP

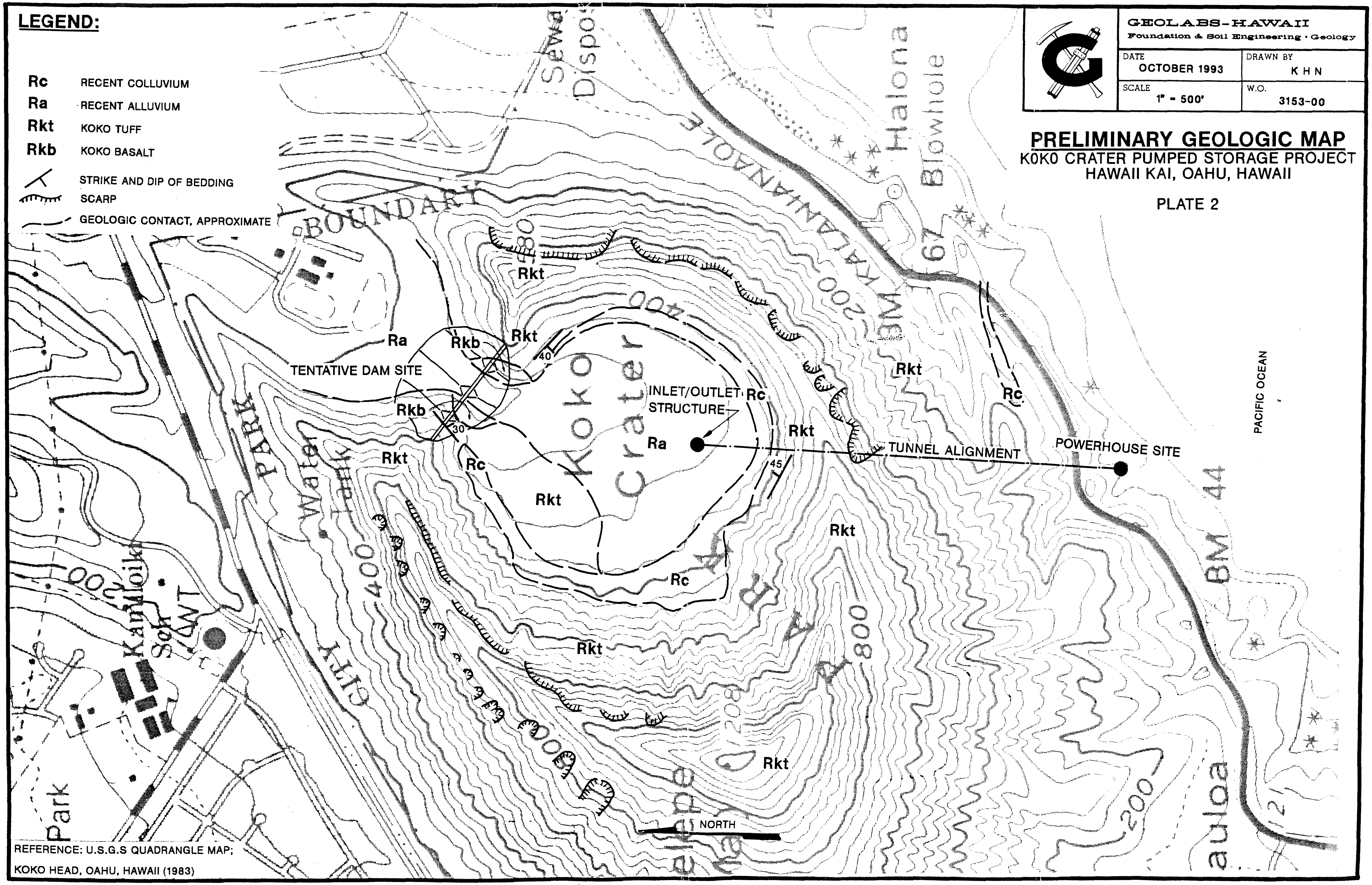
KOKO CRATER PUMPED STORAGE PROJECT
HAWAII KAI, OAHU, HAWAII

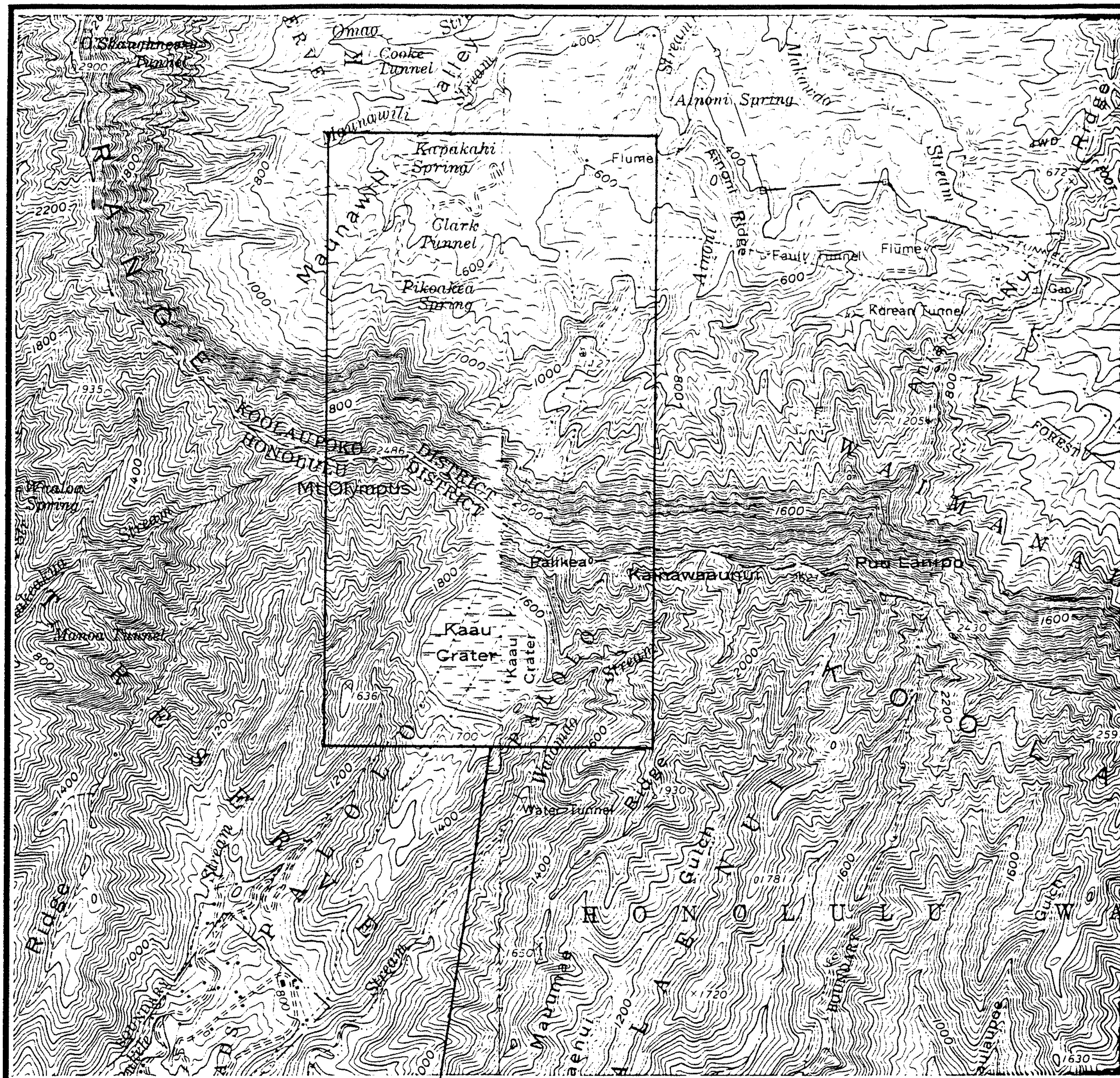
PLATE 1

REFERENCE: U.S.G.S. QUADRANGLE MAP;
KOKO HEAD, OAHU, HAWAII (1983)

GEOLABS-HAWAII
Foundation & Soil Engineering · Geology

DATE	DRAWN BY
OCTOBER 1993	K H N
SCALE 1" = 2,000'	W.O. 3153-00


LEGEND:
Rc RECENT COLLUVIUM
Ra RECENT ALLUVIUM
Rkt KOKO TUFF
Rkb KOKO BASALT
STRIKE AND DIP OF BEDDING
SCARP
GEOLOGIC CONTACT, APPROXIMATE
GEOLABS-HAWAII
Foundation & Soil Engineering · Geology
DATE
OCTOBER 1993
DRAWN BY
K H N
SCALE
1" = 500'
W.O.
3153-00
PRELIMINARY GEOLOGIC MAP
KOKO CRATER PUMPED STORAGE PROJECT
HAWAII KAI, OAHU, HAWAII
PLATE 2
TENTATIVE DAM SITE
INLET/OUTLET STRUCTURE
TUNNEL ALIGNMENT
POWERHOUSE SITE
PACIFIC OCEAN
Koko Crater
Halona Blowhole
BOUNDARY
KALANIANAOLE
NORTH
REFERENCE: U.S.G.S QUADRANGLE MAP;
KOKO HEAD, OAHU, HAWAII (1983)



GENERAL PROJECT LOCATION

N

PROJECT LOCATION MAP

KAAU CRATER PUMPED STORAGE PROJECT
HONULULU, OAHU, HAWAII

PLATE 3

REFERENCE: U.S.G.S. QUADRANGLE MAPS; HONOLULU & KOKO HEAD, OAHU, HAWAII (1983)

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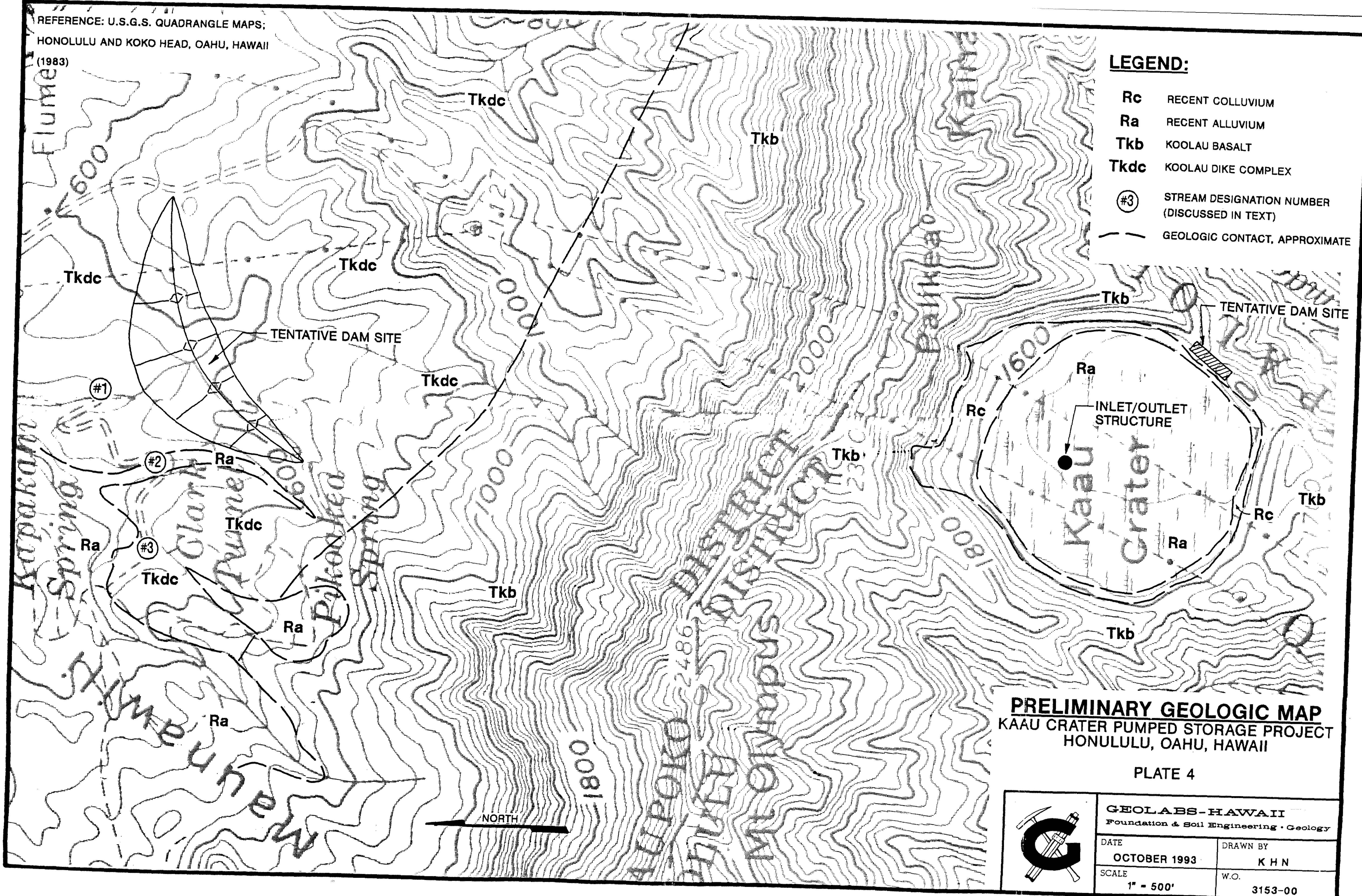
OCTOBER 1993	K H N
SCALE	W.O.
1" = 2,000'	3153-00


REFERENCE: U.S.G.S. QUADRANGLE MAPS;
HONOLULU AND KOKO HEAD, OAHU, HAWAII
(1983)
LEGEND:
Rc RECENT COLLUVIUM
Ra RECENT ALLUVIUM
Tkb KOOLAU BASALT
Tkdc KOOLAU DIKE COMPLEX
#3 STREAM DESIGNATION NUMBER (DISCUSSED IN TEXT)
GEOLOGIC CONTACT, APPROXIMATE
Flume
600
1000
1600
1800
2000
Tkdc
Tkb
Ra
Rc
#1
#2
#3
TENTATIVE DAM SITE
TENTATIVE DAM SITE
INLET/OUTLET STRUCTURE
Kaau Crater
Clark Flume
Kapakahi Spring
Pukele Spring
District
Waimea
NORTH
PRELIMINARY GEOLOGIC MAP
KAAU CRATER PUMPED STORAGE PROJECT
HONULULU, OAHU, HAWAII
PLATE 4
GEOLABS-HAWAII
Foundation & Soil Engineering · Geology
DATE
OCTOBER 1993
DRAWN BY
K H N
SCALE
1" = 500'
W.O.
3153-00